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The Shapes of AGB Circumstellar Envelopes

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A fundamental problem in understanding the formation of planetary nebulae is the remarkable change in morphology that occurs in the transition from the AGB. Mass loss on the AGB is roughly spherically symmetric, but becomes axi- or point-symmetric when the nebula forms. A compelling scenario to explain this change involves a binary companion, which may directly interact with the mass-losing star or blow jets from an accretion disk. If this scenario is correct, the companion must also perturb the circumstellar envelope during the entire AGB phase through gravitational focusing, to a degree that depends on the mass and separation. The shapes of AGB envelopes and their relics in planetary nebulae halos are therefore probes of the presence of the companion. To explore this idea we report examples of deep optical imaging of circumstellar envelopes at the tip of the AGB, and compare them with simulated images which illustrate the magnitude of this effect for a range of companion parameters. The results demonstrate the usefulness of this approach, and how it can be used to test and refine the binary scenario.

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Abstract: A fundamental problem in understanding the formation of planetary nebulae is the remarkable change in morphology that occurs in the transition from the AGB. Mass-loss on the AGB is roughly spherically symmetric, but becomes axi- or point-symmetric when the nebula forms. A compelling scenario to explain this change involves a binary companion, which may directly interact with the mass-losing star or blow jets from an accretion disk. If this scenario is correct, the companion must also perturb the circumstellar envelope during the entire AGB phase through gravitational focusing, to a degree that depends on the mass and separation. The shapes of AGB envelopes and their relics in planetary nebula halos are therefore probes of the presence of the companion. To explore this idea we report examples of deep optical imaging of circumstellar envelopes at the tip of the AGB, and compare them with simulated images which illustrate the magnitude of this effect for a range of companion parameters. The results demonstrate the usefulness of this approach, and how it can be used to test and refine the binary scenario.

Imaging AGB Envelopes

The halos of PNe and proto-PNe typically appear to be roughly spherical (Fig. 1 top row) but the shapes of AGB envelopes are not well documented. We are carrying out a project to measure envelope shapes near the tip of the AGB using deep optical imaging in dust scattered Galactic light. This is an effective technique: in the outer regions the optical depth is small, and the observed intensity depends on the column density.

Rows 2 and 3 of Fig. 1 show imaging of six AGB envelopes with high mass-loss rates, obtained with the NTT or VLT. The envelopes are typically observed to be approximately circularly symmetric, consistent with the appearance of PN and proto-PN halos. There is one exception AFGL 2514 which is distinctly elongated.

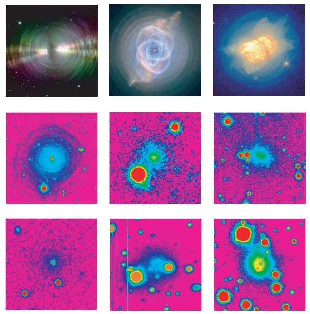

Fig 1. Envelope Shapes in AGB Stars, Proto-PNe, and PNe
Row 1: AFGL 2688, NGC 6543, NGC 7027 [1] Row 2: IRC +10216, IRAS 12384-4536, AFGL 2514 Row 3: IRC+10011, IRAS 17319-6234 IRAS 16029-3041

Simulated Envelope Images

The large scale shape of a circumstellar envelope is affected by the presence of a nearby binary companion through gravitational focusing. The observed shape depends on the intrinsic shape, the orientation to the line of sight, and the mode of observation.

We compute images for a range of binary parameters for comparison with the observations. The examples shown are for the case where the intensity depends on column density, which is appropriate for the analysis of scattered light images. For the intrinsic shape, we use an approximation given by ref. [2] for the simulations from ref. [3], and for the expansion velocity we use 10 km/s.

Figs. 2 and 3 illustrate the dependence of the observed envelope shape on the binary parameters. Fig. 2 shows the variation with companion mass and orientation of the symmetry axis to the line of sight, for a separation of 10 AU. Fig. 3 shows the variation with companion mass and separation, for a representative orientation of 60°.

Envelopes appear round when viewed nearly pole-on, but there is a large range of parameter space, especially for close companions which are expected to be common, for which the envelopes appear distinctly flattened.

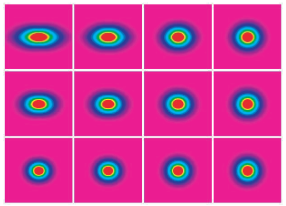

Fig 2. Envelope shape vs secondary mass and inclination
Left to right: secondary mass = 1.0, 0.5, 0.2, 0.1 M_o (separation = 10 AU)
Top to bottom: inclination angle = 80°, 60°, 33°

Implications

The observations show that most, though not all, of the AGB circumstellar envelopes observed are close to circularly symmetric in appearance. Since the expected median inclination (for random orientations) is 60°, this implies that the envelopes are close to spherically symmetric. This result is consistent with observations of approximately spherical halos around PNe and proto-PNe, which are the relics of the AGB envelopes [ref 2].

If a binary companion causes the sudden change in geometry when a PN forms [e.g. 4], it needs to be within a few AU of the AGB star for common envelope or Roche lobe overflow, or within a few tens of AU to accrete enough material to blow jets. Such a companion will also affect the shape of the AGB envelope before the transition to a PN, by gravitational focusing. The magnitude of the effect is shown in the simulated images. It is clear that close companions of intermediate or high mass will produce significantly flattened envelopes for a wide range of parameters. The absence of this effect in the majority of cases places limits on the mass and separation. Only low mass companions can orbit close to the AGB star without observable shaping, until a more direct interaction (engulfment, tides, jets) causes a sudden change in the geometry [ref 2].

We are refining these constraints by including the shaping by a population of companions of different masses and different separations, as expected at this stage of evolution.

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References

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[2] Huggins, P. J., et al. 2009, MNRAS, 396, 1850
[3] Mastrodemos, N., & Morris, M., 1999, ApJ, 523, 357
[4] Huggins, P. J., 2007, ApJ, 663, 342

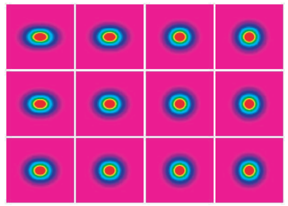

Fig 3. Envelope shape vs secondary mass and separation
Left to right: secondary mass = 1.0, 0.5, 0.2, 0.1 M_o (tilt = 60°)
Top to bottom: separation = 10, 20, 40 AU